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SECTION II.—GENERAL METEOROLOGY.

MEAN ANNUAL RAINFALL OF THE UNITED STATES WITH NOTES ON THE NEW CHART OF AVERAGE ANNUAL PRECIPITATION from the "Atlas of American Agriculture" (Advance Sheet).

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INTRODUCTION.

Rainfall maps in general.—There are difficulties in the study of the rainfall distribution over so large an area as that of the United States. Not only do the charted amounts of precipitation vary greatly in different sections, but there is still, and will be for years to come, some uncertainty as to just how much rain and snow actually fall. This is especially true of the western plateau and mountain country. Here, raingages are generally widely scattered, and are mostly at relatively low levels, so that but little can be definitely known regarding the precipitation on the mountains. These difficulties are by no means confined to the West. Even in thickly settled areas, raingage readings are known to be unsatisfactory. The local conditions of exposure, of altitude, of topography, have so marked an influence on the catch of the individual gage that the whole matter of actual rainfall distribution is much in doubt.

Rainfall maps for the United States are numerous. They differ considerably from one another. Some authorities have limited themselves fairly, or absolutely, rigidly to the observed readings of raingages. Others have based their maps on actual observations so far as these go, but have taken a further step. They have made use of all the known facts regarding topography, stream flow, wind direction, vegetation, and other conditions. These facts are taken into account in making reasonable inferences as to the amounts of precipitation over the higher mountain slopes and summits, and over unoccupied areas in general. *Isohyetal lines* are then drawn accordingly. There has thus been a good deal of divergence in the views of those to whom we owe our rainfall maps (1).

What may be termed the more strictly meteorological group has, in general, taken the position that such charts should show only such amounts of precipitation as have been actually measured. They have held that inferences regarding precipitation over areas where no records are available, necessarily largely reflect only the individual opinion of the author and lose greatly in value on that account. They maintain that, when inferred isohyetal lines are drawn over regions where there are but few stations, that fact should be very clearly indicated, a distinction being made between observed and inferred conditions. In the case of mountains whose rainfall is not definitely known, there is no reason why the area should not be left blank on the map. Or, if desired, the slopes for which observations are lacking may be inclosed by an isohyetal line whose position is definitely established, and the words "probably over — inches, or millimeters" may be entered within this line. On the other hand, the second group, which is largely composed of geographers and of those who have broad geographic conditions in mind, takes the view that the relief and all other known surface features of the country should be recognized and utilized in inferring the positions of the isohyetal lines, and that many serious errors in locating these lines, such as drawing a line across a hilltop when it should obviously go around the base, may be avoided if a contour map is used. The extent to which the topography of any region should be taken into account obviously depends on the scale of the map. The smaller the scale the fewer the details which may be shown (1).

The purpose of the present paper is to make clear the essential facts regarding the rainfall of the United States, by eliminating all unnecessary details and avoiding confusion. This discussion has, therefore, only an academic interest. The present point of view is broadly geographical rather than strictly meteorological. Hence a rainfall map which attempts, on a reasonably sound basis of topography, water supply, and vegetation, to show the inferred amounts of precipitation over areas where gage readings are lacking, is more satisfactory than one which is based solely upon actually recorded amounts of rainfall. In any study of rainfall charts it must be remembered that the transition from one color or one kind of shading to another, which stands out so strikingly on the maps, gives an erroneous impression of a suddenness of change in the amount of rainfall on the two sides of that line. The increase or the decrease in rainfall from that indicated by one isohyetal line, or by one color or shading, to that shown by the next is gradual.

In detailed studies of rainfall, as in its relation to crops, or irrigation, or water power, it is usually necessary to use maps which show the amounts of precipitation for every 10 inches, 5 inches, or even 1 inch. For more general purposes, as in a review of the larger facts of rainfall, it is simpler and generally sufficient if the distribution of certain more or less critical rainfall amounts is alone considered. This latter scheme is, for example, well adapted for use in constructing wall maps of mean annual rainfall, where the larger facts must be presented in the clearest possible way. From the point of view of man and of his relation to the mean annual rainfall it has become more or less conventional to adopt certain "critical" grades of rainfall. Such critical rainfall amounts are below 5 inches (1); 5 to 10 inches (2); 10 to 20 inches (3); 20 to 40 inches (4); and over 40 inches (5). Districts of very heavy rainfalls, of 80 inches and over (5), may be included as a separate group. Where the rainfall is less than 5 inches a year there are true deserts. Where 5 to 10 inches fall the country is arid. Agriculture requires irrigation. The available water supply is extremely limited. Only a small portion of these areas can ever be useful to man. The districts with 10 to 20 inches are generally called semiarid. Roughly, they include "dry-farming" areas, although, as shown by L. J. Briggs and J. O. Belz (2), these rainfall limits are only approximate in the United States. Many factors besides the mean annual rainfall control agricultural operations, e. g., the monthly distribution of the rain; the amount of evaporation; the temperature; the methods of cultivation; the soil, etc. Dry-farming is carried on, more or less successfully, over increasing portions of this semiarid area in the United States, and there is also a considerable use of irrigation over other smaller parts of it. The development of these areas has been rapid, and there is still possibility of great future development. Rainfalls of 20 to 40 inches are sufficient for all ordinary agricultural or water-supply purposes. Above 40 inches, and up to (say) 80 inches, the amount is abundant, and above 80 inches it may be described as superabundant. The use of some such grades of rainfall simplifies the description of ordinary precipitation charts and helps greatly in memorizing them.

THE NEW MEAN ANNUAL PRECIPITATION CHART OF THE UNITED STATES.

What will, for many years to come, be the standard chart of mean annual precipitation for the United States has recently been published (this REVIEW Chart XLV—76). It is an "advance sheet" (January, 1917) from the forthcoming Atlas of American Agriculture. It embodies the best and the latest information which is now available. It recognizes the absolutely essential importance of using only records covering a uniform period or reduced to a uniform period.[1] In the location of the isohyetal lines it takes reasonable account of topography and of other conditions which indicate, or which control, the amount of precipitation. Printed in eight shades of blue (under 10 inches; 10 to 15 inches; 15 to 20 inches; 20 to 30 inches; 30 to 40 inches; 40 to 50 inches; 50 to 60 inches; over 60 inches), with isohyetal lines drawn for every 5 inches, on a base map 24 by 16 inches showing the topography clearly and in ample detail, with the names of all the more important mountain ranges and individual mountains given, the new map is not only in itself interesting and pleasing cartographically, but it brings out many details of rainfall distribution which make its close study well worth while. The records of about 1,600 stations for the 20-year period 1895–1914 have been used, together with 2,000 additional records from 5 to 19 years in length. The latter series, it is most satisfactory to note, have been "uniformly adjusted to the same period," i. e., they have been reduced to the same uniform period of 20 years. This reduction, which is inevitably a very laborious piece of work, the large number of stations employed and the use of records through the year 1914 combined, make the new chart by all means the most accurate one which is available for the United States. Careful distinction is made, by symbols, between the different classes of stations. A small inset map (6 × 4 inches) shows the percentage of annual precipitation occurring between April 1 and September 30 (five shades of color), and was compiled from the records of about 1,600 stations, 1895–1914. An inset diagram shows the period of the year within which 50 per cent of the annual precipitation occurs in 12 districts. The text which is to accompany this new map has not yet been published. The discussion which follows therefore is not based on the official descriptive text which will doubtless soon be available for distribution.

[1] The principles recognized and followed in preparing the accompanying new annual rainfall chart are set forth by its authors in the paper "The preparation of precipitation charts," by Wm. G. Reed & J. B. Kincer, MONTHLY WEATHER REVIEW, May, 1917. 45:233-235.

CLIMATIC PROVINCES OF THE UNITED STATES.

The rainfall of the United States is best considered, not by taking the country as a whole, but by dealing with certain large subdivisions individually. The subdivisions here used are those suggested by the present writer in 1915, and shown in figure 1 (3).

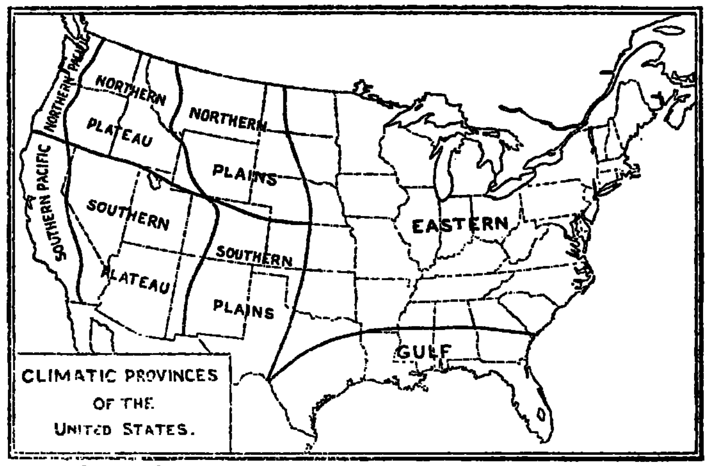

FIG. 1.—Climatic provinces of the United States. (R. DeC. Ward.)

RAINFALL OF THE UNITED STATES.

Eastern and Gulf Provinces.

Source of moisture.—The isohyetal lines over the eastern and especially the southeastern United States show a general parallelism with the trend of the Atlantic and Gulf of Mexico coasts, which is highly significant. They "head up" to these two bodies of water. They spread out from the Gulf of Mexico toward the interior. This fact, together with the distinct decrease in rainfall with latitude northward from the Gulf, and the decrease with longitude westward from the Atlantic, clearly indicates that these two sources of water vapor are absolutely essential in supplying the precipitation over this section of the country. Of these two bodies of water, the Gulf of Mexico is the more important. From that source comes, directly or indirectly, the bulk of the rain which falls from the Rocky Mountains eastward and southward. From St. Paul, Minn., to New Orleans, La., the mean annual rainfall [precipitation] increases by nearly 30 inches. The influence of the Atlantic Ocean is clearly seen along the eastern seaboard, extending inland to the Appalachians, especially over the northern sections of the coast. It is probable that the bulk of the direct supply from the Atlantic does not extend inland to any considerable extent beyond the Appalachians. From Eastport, Me., to St. Paul, Minn., the decrease in mean annual rainfall is about 15 inches. The Great Lakes are a subordinate and *relatively* unimportant source of rainfall.

The importance of the Gulf of Mexico and of the Atlantic Ocean in supplying the moisture which, owing to the western mountain barriers, is prevented from coming far inland from the Pacific, can not be overemphasized. Taken as a whole, a remarkable combination of favorable conditions exists for producing abundant and well-distributed rainfall over the eastern United States. First, the warm waters of the Gulf of Mexico—

occupying latitudes which, with a different distribution of land areas, would be an American Sahara—and the Atlantic Ocean, kept at a relatively high temperature along a considerable extent of the coast by the warm Gulf stream, are near-by sources of a plentiful water-vapor supply. Second, the prevailing winds during the most critical season of the year (summer) blow—with an almost monsoon like persistence—from the warm waters of the Gulf of Mexico, at high temperatures and well laden with water vapor, far into the interior of the continent. Third, the topography of the eastern half of the country offers no serious obstacle anywhere to the free flow of these winds. Fourth, the ordinary cyclonic storms of the "prevailing westerly" winds play a very important part in the control of precipitation, especially in winter. At that season, when the pressures are high, the prevailing winds blow out from the continent and the continental type of climate tends to give cold, dry, and clear weather, the numerous and well-developed cyclonic storms, with their damp easterly and southerly winds from the Atlantic, and from the Gulf, bring rain or snow which, under non-cyclonic controls, would never fall. In summer the cyclonic control is weak; but there is then much less need of this source of rainfall, for the continental pressures are low, the prevailing winds are onshore, are very warm, and supply plenty of moisture themselves. Nevertheless, the fewer and weaker cyclones of the warmer months intensify the southerly indraft, and favor the occurrence of local showers and thunderstorms.

No mountain barriers.—The rain-shadow effect of the western mountains would prove a very serious climatic handicap to the region lying to the east of the Rocky Mountains if it were not for this remarkable combination of conditions. In eastern Asia, in latitudes 30° to 40° N., there is a district climatically similar in many respects to the eastern United States in the same latitudes. Yet in Asia, owing to an absence of some of the favorable controls which are so striking in North America, the area with precipitation over 40 inches is greatly restricted. In western Europe, on the other hand, there are no high western mountains. Hence there are no such marked rain-shadow effects as in the United States. Hence, also, there is no similar need for a new moisture supply for the interior sections such as exists in the United States. The Mediterranean Sea seems analogous to the Gulf of Mexico, but the influence of the former is fairly well shut out from the interior by the mountain barrier of southern Europe. It is very fortunate for the United States that there is no transverse mountain barrier, like the Alps, stretching across the Mississippi Valley. In Europe teh Alpine barrier is not a climatic handicap, because the moisture supply from the Mediterranean is not essential to the countries lying to the north.

General distribution.—The extraordinarily favorable rainfall conditions which prevail over the eastern United States have inevitably attracted the attention of almost all writers on the climatology of North America. Prof. W. M. Davis has stated the case none too emphatically when he says: "Although droughts sometimes affect considerable districts, and floods occasionally devastate the larger valleys, yet the world hardly contains so large an area as this, so well adapted to civilized occupation." (4)

Everywhere over this great area the rainfall is over 20 inches; about one-half the area receives more than 40 inches; no inconsiderable portion has more than 50 inches; in restricted localities the amounts exceed 60 inches. The rainfall is greatest (in general, 50 to 60 inches) over the Gulf States, with the exception of Texas, and along most of the immediate seaboard of the Carolinas and Georgia. It decreases from these amounts, and from 40 to 45 inches over most of the northern and central Atlantic coast; to 30 to 40 inches over the prairies; and to 20 inches at about the 100th meridian. In the West the isohyetal lines trend nearly north-south. The heavier rainfalls, excluding those due to topographic controls, are thus found near the bodies of water which supply the moisture. From Florida, along the eastern and northern Gulf coasts to the southwestern corner of Louisiana, the amounts vary between 50 and 60 inches. Most of Louisiana, Mississippi, and Alabama, and a good deal of southern Arkansas, have over 50 inches. Along the Texas coast there is a very rapid decrease from 50 inches in the northeast to 20 to 25 inches in the extreme south, the isohyetal lines trending very nearly north and south. This Texas section is not nearly as favorably located with regard to rainfall as is the rest of the Gulf coast, both in the matter of its exposure to the prevailing damp winds blowing across the Gulf and in its relation to cyclonic storms. Along the Atlantic seaboard, the amounts decrease somewhat with increasing latitude, from 55 to 60 inches in extreme southeastern Florida to 40 to 45 inches in Maine.

Appalachians.—The influence of the Appalachian Mountains is indicated in the irregularity of many of the isohyetal lines, and in the occurrence of certain local areas of heavier or lighter precipitation. As a whole, however, since the mountains are not very high, and since their trend is approximately parallel with that of many of the rain-bearing winds and with the tracks of numerous cyclones, it is not to be expected that there should be any very marked differences in rainfall on the opposite slopes. The most marked topographic control over rainfall in the Appalachians is in a small area along the southern and eastern slopes of the mountains of southwestern North Carolina, northwestern South Carolina, and northern Georgia. In this elongated area the rainfall amounts increase from 50 and 55 inches over the lower slopes to 60 inches at greater elevations, reaching 80 inches at a maximum in one small area in the mountains of the southwestern corner of North Carolina. This is the maximum mean annual rainfall anywhere east of the Sierra Nevada-Cascade divide. A combination of topography and of exposure to rain-bearing winds doubtless explains this interesting peculiarity. Far away to the north, the White Mountains of New Hampshire (Mt. Washington) stand out as a small district of heavier precipitation (50 to 60+ inches), and in New York State the position of the Adirondacks is clearly indicated by the isohyetal lines of 45 and 50 inches. The higher parts of the Cumberland Plateau in Tennessee, have over 55 inches, and there are other less important areas with somewhat increased precipitation, e. g., the mountains of West Virginia. Noticeable, also, are the effects of the topography in causing somewhat diminished rainfall. The Hudson-Lake Champlain depression is clearly marked, with less than 30 inches in the north. The inner longitudinal valleys of Virginia and West Virginia stand out sharply with their 40 and even 35-inch isohyetal lines, a rainfall 5 to 10 inches or more below that of the surrounding mountain country. The plentiful rainfall over the Appalachian area as a whole furnishes abundant water power in numerous well-filled rivers, and thus becomes an important factor in the industrial development of the eastern States. The only other striking topographic controls over rainfall in the eastern United States are seen in the deflection of the 50-inch line over the Ouachita Mountains of central Arkansas and in the local increase of rainfall from 40 to 50 inches over the Boston Mountains in the northwestern part of the same State.

Great Lakes.—The chart does not indicate any very striking influence of the Great Lakes on the mean annual precipitation in their immediate vicinity. This fact was pointed out many years ago by Blodget. In 1899, Prof. A. J. Henry wrote: "The Lakes themselves, with the possible exception of Lake Superior, do not seem to have a very marked influence on the precipitation of moisture on adjacent land areas" (**5**). The lee shores of the Lakes in several cases show a somewhat heavier annual rainfall, but relatively the excess is a rather small amount, generally not over 5 inches. The Lake effect is probably greatest in the case of Lake Superior. Local topography is here, as always, an important factor in determining the amount of rainfall. There is a rather significant widening toward the Lakes, of the belt between the 30 and 35-inch isohyetal lines and, to a somewhat less marked degree, of that between the 35 and 40-inch lines. This fact, together with the general trend of the lines in the Lakes region, indicate, that the Lakes influence is present although it is not striking. It should be borne in mind that the rainy winds are to a considerable extent from easterly directions, and for that reason the lack of any very decided influence of the "prevailing westerlies" is not surprising. It is to be expected that in winter, when the westerly winds blow across the open water of the Lakes, the snow will be heavier on the lee sides. It may be observed that the Great Lakes are not bountifully supplied by many large rivers. Hence they are very dependent for their water supply upon local rain and snowfall. An interesting point regarding the Great Lakes was brought out by Blodget (**6**), when he wrote that they "could not exist if extreme continental features of climate were ever fairly developed there." In other words, the Lakes occupy a district which naturally has a well-marked continental climate and unless the extremely favorable conditions for rainfall which have been explained above, were present there would be a deficiency of rainfall here. These conditions result in a modification of the continental characteristic of deficient or light rainfall; the Great Lakes basins are well filled and the Lakes, in their turn, modify the local climates.

Population.—The bulk of the population of the United States is found in this eastern section (embracing the Eastern and Gulf Provinces), where the mean annual rainfall ranges between 20 and 50 inches. Here sufficient moisture favors successful agriculture, with annual summer crops raised by ordinary farming methods. Here the rainfall is favorable so that the agricultural provinces are based largely on temperature and therefore in general follow the latitude lines; latitude and soil being the principal crop controls (**7**). It is the sufficiency of the rainfall, combined with its favorable distribution through the year, that is of such inestimable advantage to agricultural prosperity. The generally abundant spring and early summer showers; the prevailingly high summer temperatures; and the plentiful supply of atmospheric humidity; combine to produce an almost semitropical type of summer climate very favorable, in the South, for sugar cane and for cotton and, farther North, for wheat, corn, oats, and other cereals. It has been well said that "there is no great area so far in the interior which presents a similar result"(**6**).

Rainfall of the Great Plains.

Distribution.—The general east–west and northeast–southwest trend of the isohyetal lines over the Southern and Eastern States becomes a roughly north–south trend over and somewhat to the east of the Great Plains, and continues to be the general characteristic all the way to the Pacific with, of course, many local irregularities due to topographic controls. The isohyetal lines may be thought of as swinging on a pivot located over the western Gulf States, their eastern free ends traveling north, northwest, and west until they reach an approximately north–south position. The 20-inch line, because of its critical controls over vegetation, is often taken as the eastern boundary of the Great Plains. It lies in a general way along the 100th meridian, but is east of it in the Dakotas, and west of it in the remaining States to the south. Hence, along the 100th meridian, the rainfall is between 15 and 20 inches in the north, and about 25 inches in Oklahoma and most of Texas. This difference between north and south naturally points to the Gulf of Mexico as the source of the rainfall. There is, thus, over the Plains as a whole, no change of rainfall with latitude; no decrease, as there is farther east; no increase, as there is farther west. The Rocky Mountain divide roughly separates these two contrasted relations of rainfall and latitude. Over the Plains, owing to the increasing distance from the chief source of moisture, the rainfall as a whole decreases toward the west, in spite of the fact that the altitude increases, falling to 10–15 inches over much of eastern Montana, Wyoming, and Colorado.

Orographic controls.—For the sake of simplicity and convenience the "Plains Province" may be limited on the west by the Continental Divide (see fig. 1). In such a scheme of subdivision, much of the so-called Plains Province includes a highly varied mountain topography, with mountain climates, and many marked cases of topographic controls over rainfall. At a first glance the rainfall map gives the impression of complexity and confusion, but a more careful examination of its details leads to the following simple statement. The more marked, i. e., the higher, topographic features are clearly local centers of heavier precipitation, but the amounts are in no case excessive (20 to 25+inches) in any degree. Several mountain groups are clearly indicated by their heavier rainfalls. Such are the Black Hills of South Dakota; the Lewis Range and the Little Belt Mountains of Montana; the Absaroka and Wind River Ranges and the Big Horn Mountains of Wyoming; the Front, Park, and Sawatch Ranges, and Pikes Peak in Colorado; the Sangre de Cristo Mountains of Colorado and New Mexico. The Black Hills, so named because of their dark forests which result from the heavier rainfall, are a center of lumbering in the midst of a surrounding treeless country of cattle or sheep ranges. Elsewhere, also, the increased precipitation of the greater elevations makes possible forest growth. The "parks" of Colorado, for example, have sufficient precipitation to support a growth of pines which add greatly to the natural beauty of these intermont basins. A few districts which are topographically unfavorably situated, have less than 10 inches of rainfall. Such are the Big Horn and Green River districts of Wyoming; and a smaller area between the Sangre de Cristo and San Juan Mountains in Colorado.

Relative dryness.—Too far from the Atlantic and the Gulf of Mexico on the one side to be able to receive an abundant supply of moisture from those sources, and too far and too well shut off from the Pacific on the other to be able to draw upon that source, the Plains must inevitably be relatively dry. Storms cross them, it is true, especially in the north and in winter, but precipitation can not be heavy when the inflowing winds do not carry much moisture. The somewhat more abundant rainfall of the loftier mountains is an important source of supply for the rivers whose waters are used for irrigating the lower country to the eastward. An annual rainfall of 20 inches, combined with high summer temperatures, marks about the limit below which permanently successful agriculture on a large scale and without irrigation, as practiced over the great farming lands farther east, is not possible. To the west of the 20-inch isohyetal line, therefore, over the Plains, there is a vast region where agriculture of the type characteristic of the rainier east is as a whole no longer found (except on the northern Pacific coast); where water, not land, is the measure of success. Over all this great western area the agricultural provinces are determined by altitude and rainfall. They therefore extend roughly north and south, as do the mountain systems; and not east and west under the control of temperature, as they do in the east (**7**). Dry farming, grazing, irrigation are man's three methods of making use of the land. Dry farming, where the rainfall is most abundant; stock raising, where there is not enough moisture even for dry farming; irrigation, over the limited areas where water is available. Once the home of immense herds of bison which pastured on the natural grasses; then browsed over by millions of cattle; later, in the days of the "boom," the scene of unhappy and disastrous attempts to use them for large-scale agricultural operations of the eastern type; the natural limitations of the Great Plains have come to be fully recognized. They were never fitted to be a region of vast farms for raising crops by methods which take no account of the special *climatic and soil* limitation (**8**). They could not continue to support vast herds of cattle which exhausted the natural pasturage. They are available, here for dry farming; there for local irrigation from streams or wells, with small individual farms and cattle ranches, each farm having its own cultivated patch of cereals, and vegetables, and fodder for the cattle; and elsewhere, again, for grazing.

It has been pointed out by Henry (**9**) that, while no *hard and fast rule can be laid down*, the line of 15 inches of rainfall per crop-growing season very broadly defines the area which is devoted to the cultivation of cereals in the United States. Yet the very remarkable crops harvested in the Red River Valley are produced with a less amount, and in the dry-farming wheat region about Spokane, Wash., the rainfall in April–June averages 4.5 inches, which is about that of a single month in the Mississippi Valley wheat country. In discussing the relation of spring-sown wheat yield to rainfall on the Great Plains, Messrs. Briggs and Belz (**2**) conclude that when the rainfall for April–July, inclusive, is less than 8 inches, the yield barely suffices to cover the expense of producing the crop. It is significant that the heavier precipitation of the eastern United States, combined with favorable conditions of temperature and soil, produced a great natural forest cover which the early settlers were obliged to clear away. This was a slow and laborious task, and greatly delayed the progress of white settlement. In the West, on the other hand, over the treeless areas of the Great Plains, for example, there was no such obstacle. Vast stretches of the West were available for rapid occupation, for grazing, or for agriculture. The difficulty here is the impossibility of supporting a large population, owing to the deficient rainfall.

The Plateau Province.

Over the western Plateau Province, with its varying topographic features, its rugged slopes, and its sparse population, the rainfall is still but imperfectly known. This is distinctly a rain-shadow area, of generally deficient precipitation. It is desert, arid or semiarid, except when the higher mountains or plateaus provoke a more abundant rainfall, specially in the north where the mountain barrier is less effective and the storms are more numerous. The moisture which, if it were not for the western mountain barriers it would receive from the Pacific, in great part falls as rain or snow on the windward slopes of these mountains, on the narrow Pacific slope. Even the most superficial comparison of the topographic and the rainfall maps of the Plateau Province shows at once a remarkably *close correspondence* between them. In many respects the lower valleys and plateaus of this region are comparable, as pointed out by Voeïkov, with the Aral–Caspian lowland. The most extreme deserts of the Old World are, however, more absolutely barren than the North American deserts.

Northern division.—It is convenient to consider the Plateau Province in two divisions, the northern and the southern (see fig. 1). The most striking feature on the *precipitation map is the increased rainfall over the* dominant mountain groups of Idaho (Bitter Root, Clearwater, and Salmon River Mountains) and of eastern Oregon (Blue Mountains). Annual amounts of 30 and 35 inches are shown over the upper slopes, with the isohyetal line of 40 inches inclosing a portion of the northern Bitter Root Range. These are the largest amounts (40 inches) shown anywhere in the Rocky Mountains area. Over the districts of least elevation, the Snake River Plains in southwestern Idaho, the great plains of southeastern and central Oregon and central Washington, rainfalls of less than 10 inches occur. Lying between the somewhat more abundant rainfall on the mountains and the too-great aridity of the districts with less than 10 inches, a fair portion of eastern Oregon and Washington, and of southern Idaho, has 10 to 20 inches. In certain of these districts dry farming has been carried on with a considerable degree of success, especially in the newly developed and fertile agricultural region of eastern Washington. Messrs. L. J. Briggs and J. O. Belz (**2**) have concluded that, with the evaporation which occurs in the Great Basin, a mean annual rainfall of 13 inches is about the *minimum* for profitable dry farming. In the basin of the Columbia River, in southern Washington and northern Oregon, wheat is successfully grown by summer-fallowing methods, with a mean annual rainfall of 10 inches, and the minimum for any profit at all seems to be about 8.50 inches. As these authors point out, there is probably no other part of these States where dry farming is practiced with so small a rainfall as this.

Land with too little rainfall even for dry farming, and which can not be irrigated, is to a considerable extent used for grazing, and irrigation has brought great prosperity to a number of communities which have become famous for their fruit crops, e. g., the Yakima Valley, in Washington. A railroad trip of great interest may be taken from the famous dry-farming wheat country around Spokane; southward on the treeless lava plateau; across the Columbia River, and then westward and northwestward up the valley of the Yakima River in the lee of the Cascade Mountains. Here man has turned the "desert" into one continuous garden. Here the wonderful orchards of apple, peach, and pear trees, the fields of hops and of alfalfa, and the vineyards reaching for miles and miles in every direction, make the traveler realize that the glowing accounts which have been given of this region are not greatly exaggerated. Upon the summits and upper slopes of the Cascades there is a rainfall 10 or 15 times as great as that in the valleys at the eastern base—a rainfall resulting from the presence of the mountains across the path of the rain-bringing westerly winds. It is this water which has been collected for the use of man in the Yakima irrigation projects. The interest of the climatologist in this Yakima country is not so much in the number of carloads of fruit which are sent out, or in the size of the apples and pears and peaches, but rather in the relation of the dry, leeward, rain-shadow valleys to the well-watered mountain summits, and in the curious overlapping of the forests from the rainy western slopes into the higher portions of the valleys on the eastern slopes.

The Rocky Mountains as a whole, it should be noted, are not nearly as important controls of precipitation as might at first be expected. They are, in general, so far from the Pacific that their rainfall is not heavy. They are, furthermore, to leeward of the very considerable ranges of the Sierra Nevada and the Cascades. The rain-shadow effect of the Cascades is strikingly shown on the rainfall map in the contrast between the rainy western and the dry eastern slopes in Washington and Oregon.

Southern division.—The southern division of the Plateau Province is distinctly drier than the northern. With the exception of some local areas in the mountains the rainfall is less than 20 inches, mostly below 10 inches; over no insignificant portion it is even below 5 inches. Well removed from the most frequented track of cyclonic storms; in the lee of the great Sierra Nevada; shut off from the free access of rain-bearing winds; it is no wonder that this great province should be arid. This was all known, not many years ago, as the "Great American Desert." It is a region of interior drainage; of peculiar topographic forms dependent on the climate; and of Great Salt Lake, the feeble relic of a great ancestor, Lake Bonneville. The real "American Desert" lies in southeastern California, the southwestern angle of Arizona and western Nevada. If the continent were broader, there would be a much larger desert in these latitudes. The mean annual rainfall is only 5 inches. Death Valley is here, with its famous borax deposits and its intense summer heat. The Salton Sea is here—an anomaly in a true desert—originally supplied through the Colorado River by water which fell as rain or snow on the slopes of the Rocky Mountains far to the east; evaporating rapidly under the clear skies and high temperatures. The Black Rock desert; the "sinks" and the soda deposits of western Nevada are here.

Surrounding the "desert," with its hopelessly deficient rainfall, comes a considerably larger area with 5 to 10 inches—also arid and impossible for agriculture and for settlement without irrigation. This includes most of Nevada, western Utah, a strip across western Arizona, and other areas of relatively moderate elevation in northern Arizona, New Mexico, eastern Utah, and southwestern Wyoming. Over the higher mountain slopes and plateaus the amounts exceed 20 inches, locally; as across the central portion of the Arizona plateau, on the Wasatch and Uinta Mountains of Utah, the Absaroka, Wind River and other ranges of northwestern Wyoming (over 25 inches on the Absaroka Range), and the San Juan (over 30 inches) and other mountains of western Colorado. Intermediate rainfalls, from 10 through 15 to 20 inches are found distributed, in close agreement with the topography, over the intermediate altitudes. A topographic map is here a good rainfall map, and also a good vegetation map. For, while the lower-lying portions of this whole region are dry and barren, the increased precipitation over the more elevated plateaus and on the mountains, supports grass and often forests. Arizona, which rises more or less like a flight of steps from the southwestern corner, shows this relation very clearly. From a mean rainfall of less than 5 inches in its southwest, the amounts gradually increase to over 20 inches. The so-called "islands"—much more appropriately termed "lakes"—of heavier precipitation on the mountains are economically of great importance. They supply the water, chiefly melted snow, which is used for irrigating the arid lowlands. Phoenix, Ariz., for example, receives on the average less than 8 inches of rainfall annually. Over the watershed behind the Roosevelt Dam perhaps twice as much rain falls. This extra supply, resulting from the presence of the mountains, when carefully collected, stored and distributed, makes the glory of the Salt River Valley of which Arizona is so justly proud.

Wherever, throughout this province, the streams, supplied by the melting snows of the higher mountains, afford sufficient water for irrigation, bountiful crops await the farmer. But the water supply is limited, and many of the far too optimistic hopes for the future of the region have already been disappointed. Only where there is mineral wealth, in the form of precious metals or of salts, is there any value in land which has insufficient rainfall for farming and which can not be irrigated. The most valuable portions of the Plateau Province are those with 10 to 20 inches of rainfall.

Rainfall of the Pacific coast.

Rainfall and topography are also very closely related on the Pacific slope. The heaviest rainfalls in the United States (over 120 inches) occur on the Olympic Mountains of northwestern Washington. These are also among the heavy rainfalls of the world. More than 100 inches are indicated on the map for two small localities on the northern Coast Range of Washington and Oregon. Elsewhere the largest amounts are 80 inches. These are shown over the higher slopes and summits of the Cascade Range; over a small portion of the northern Sierra Nevada, and on the Coast Range as far south as northern California.

To the south, the rainfalls on the mountains decrease rapidly; although, as compared with the lowlands, they remain relatively very heavy. The 50-inch line on the Sierra Nevada does not extend south beyond the latitude of San Francisco; the 30-inch line reaches a little beyond the latitude of Fresno. The mountains of southern California are clearly shown on the map by their rainfalls of over 25 inches. Many streams, deep and swiftly flowing, rush down the slopes of these Pacific coast mountains, supplying water power, vast and never failing. The name of the Cascades at once suggests heavy precipitation. Here, in the future, when lumbering has ceased to be the chief industry, the varied manufacturing and industrial enterprises of a more complex and more thickly settled community will be developed by means of this water power, one of the most important assets of the Pacific slope.

Beautiful climatic cross sections, contrasting the rainy windward and the dry leeward sides, may be obtained when crossing either the Cascades or the Sierra Nevada by train. The contrast between the treeless lower lands east of the Cascades in Washington, and the densely forested western slopes is wonderfully impressive. In traveling by train from The Dalles of the Columbia River down the river to Portland, Oreg., the change in the character of the vegetation is an excellent "car-window" observation of the increase of rainfall, which just about trebles between The Dalles and Portland (15 to 45 inches). The gorge of the Columbia River, it may be noted, is distinctly indicated by the isohyetal lines on the rainfall map. Again, in crossing the Sierra Nevada Mountains on the Central (Southern) Pacific Railroad, going east from San Francisco, the traveler can not fail to notice that the green slopes and forests of the Pacific side are rapidly replaced by the sagebrush and allied forms of vegetation on the east. From a precipitation of about 50 inches the descent takes place with remarkable suddenness into the Nevada desert, with its alkali flats, its dust and its less than 10 inches of rainfall. Railroads crossing these mountains are not infrequently subjected to heavy expenses on account of washouts resulting from the heavy rainfalls. Occasionally local landslides, caused by excessive downpours, add to the difficulties.

Cause of heavy rain.—The heavy rainfalls of the northern Pacific coast are similar in origin to those of the coasts of Scotland, of Norway, of Chile. The close proximity of the Pacific Ocean, from which the prevailing winds blow; the frequency, especially in winter, of cyclonic storms whose in-flowing winds, from several quarters, are well charged with moisture; the mountain barriers in the path of the onshore winds—these are the dominant controls. In winter, the land, especially the high land, is usually colder than the ocean and hence the onshore winds readily become damp and rainy. This condition combines with the greater storminess of the winter months to produce the Pacific type of rainfall, with its well-marked winter maximum. Even if there were no high mountains over the northern Pacific coast, the rainfall would doubtless still be ample for agricultural needs. The storm control is not dependent on topography. The southern portion of the Pacific coast is drier for several reasons. It is beyond the reach of most of the rain-bringing storms which pass across the northern sections. The lands, and even the mountain slopes, are warmer for much of the year, especially in summer, than the ocean, and the onshore winds therefore become drier and warmer. The prevailing winds also have a considerable northerly component, and are, for that reason, warming and hence drying winds.

In low latitudes within the easterly trade-wind belts, mountains on the western border of a continent, as, e. g. the Cordillera of South America, obviously have no rain-shadow effect on the interior. In the belt of "prevailing westerly" winds, *per contra*, a western mountain barrier, especially a double western mountain barrier, must necessarily become a marked rainfall divide, as in the United States. In Europe, with its more open western borders, there is no very marked rain-shadow effect. Scandinavia alone, with its drier interior (eastern) districts, presents a weak analogy with the United States.

Southern California.—The smallest rainfalls on the Pacific slope (excluding southeastern California) are those of the San Joaquin Valley (under 10 inches). This is clearly a topographic, rain-shadow effect. Going northward up the Valley of California, the rainfall gradually increases. Over most of the lower portions of the Sacramento Valley it is between 15 and 20 inches. The surrounding slopes all show heavier rainfalls, and the amounts increase rapidly at the northern end of the Sacramento Valley as the altitudes increase. San Diego, on the extreme southern coast, has about 10 inches. The increase, with latitude up to 100 inches on the coast of Washington, is just the opposite condition to that which is found on the Atlantic coast, where there is a decrease from Florida to Maine. The Willamette Valley of Oregon has less rainfall than the mountain ranges on both sides, but is abundantly watered (40 to 50 inches). In the extreme north and the extreme south of the intermontane lowlands of western Washington and Oregon there are small areas, distinctly topographically controlled, of less than 30 inches. In the Rogue River Valley, in southern Oregon, some of the fruit growers irrigate with a rainfall of about 30 inches.

Irrigation is absolutely essential over large sections of southern California. Of vast importance in the economic value of the southern counties of California is the very heavy winter snowfall on the Sierras. This supplies many streams that flow out over the lowlands and is the source of abundant water for power, for irrigation, and for city and household use. The Sierra Nevada Mountains well deserve their name. To them California owes much, if not most of her present propserity and of her promise for future growth and development. The many feet of winter snowfall which accumulate on these upper slopes mean millions upon millions of dollars each year to the farmers and fruit growers of southern California. Were all this precipitation to fall as *rain*, every Winter would witness devastating floods, and every Summer would wither and destroy the crops. On the western slopes of these mountains are found the "Big Trees." North of San Francisco, on the western slope of the Coast Range, are found the famous redwoods; and the "Oregon pine," from farther north, is known the world over because of its usefulness for ships' masts and spars. The amount of rain and snowfall, it should be noted, does not increase at a uniform rate all the way up the western slopes to the summits of the highest mountains. In his careful hydrographic work in connection with the Los Angeles aqueduct, C. H. Lee (**10**) has found that—

> precipitation on the west slope of the Sierra between the Yuba and Tuolumne Rivers increases at a variable rate, which, expressed as an average, is 0.85 inch per hundred-foot rise from the floor of the Great Valley to the 5,000-foot contour. Above the 5,000-foot contour it decreases approximately at the rate of 0.40 inch per 100-foot rise to the crest of the Sierra.

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551.55 (747)

SEA BREEZE ON EASTERN LONG ISLAND.

By ERNEST S. CLOWES.

[Dated: Bridgehampton, Long Island, May 4, 1917.]

While quite a little study has been given to the sea breeze in the Temperate Zone I have not yet found any series of observations recording the temperature values at varying distances from the sea coast at any particular time during the sea breeze's progress inland. Records have been kept of its actual velocity and of the velocity of penetration and of its depth, but the temperature factor has been largely covered with the banal generalization that the effect of the breeze is to lower the temperature considerably.

For several years I have kept a Draper recording thermometer during the summer months at the locality known as Mecox, about 2 miles south of the village of Bridgehampton, Long Island, N. Y., and about 100 miles east of New York City. The thermometer has been well sheltered in a covered porch exposed to the southwest. It is distant about a quarter mile from the ocean by the shortest line, but about one-half to three-quarters in the prevailing direction of the sea breeze, that is southwest. The coast at this point and for miles in both directions runs about ENE and WSW. The country is generally level, open farming land for about 4 miles back from the sea, where after already having risen about 60 feet above tide the land breaks into a row of tree-covered hills about 200 to 280 feet in height. The last three summers on Long Island were generally so cool and damp that sea-breeze days were rather rare, but the month of July, 1912, was a sea-breeze month par excellence and most of the observations here recorded were made at that time.

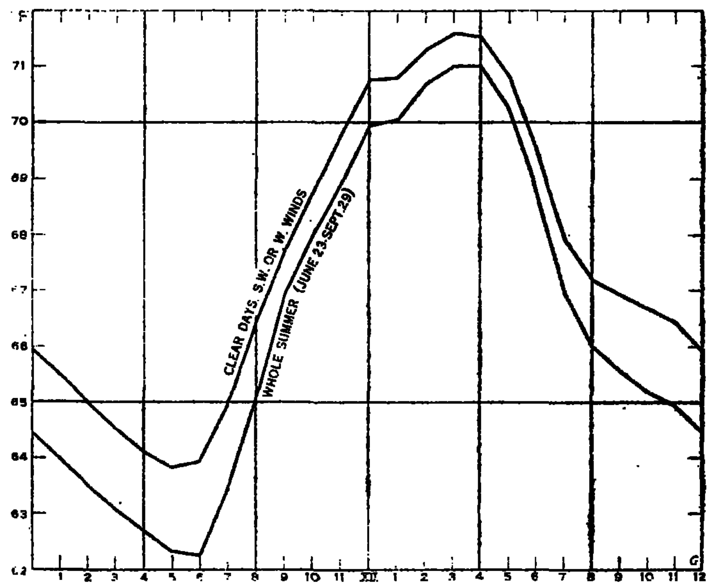


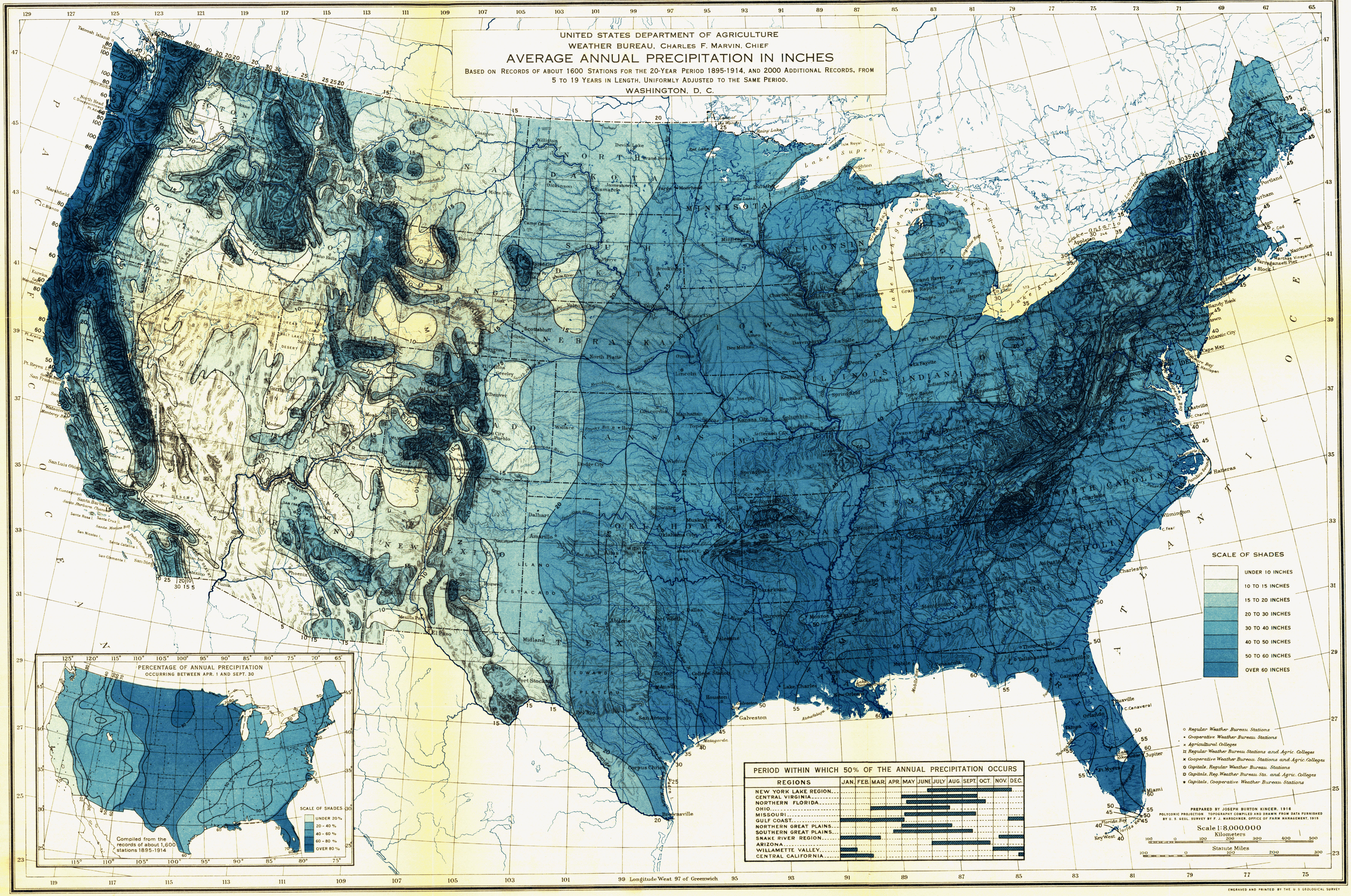
FIG. 1.—Daily temperature curve at "Hopewell," Bridgehampton, L. I. Upper curve based on 70 clear days with southwest or west winds. Lower curve average of the summer, June 23 to Sept. 29, inclusive.

The following series of daily temperature curves shows strikingly the effect of the sea breeze on temperature.[1] Figure 1 shows the average daily curve at Mecox from June 23 to July 21, 1912, a period of almost uninterruptedly fine, warm weather. The double maximum effect is clearly shown. Another interesting feature is the flattening out of the curve between 8 and 9 p. m. This is characteristic of sea-breeze weather, some days even showing a higher temperature at 9 than at 8 p. m. This is due to the cessation of the sea breeze about sun-down and the turn of the wind, usually very light, toward the land. This is not a true land breeze, for the air over the land is warmer than over the sea, but rather a return of the wind to its normal direction.

Figure 2 gives curves which show the average hourly temperatures at certain Weather Bureau stations for the same period June 23—July 21, 1912 in comparison with that at Mecox. This comparison presents interesting features. Besides Mecox, the only other curve that presents a double maximum is that for Atlantic City which gives nearly a triple maximum. This is also a

[1] The author would here acknowledge his obligations to the U. S. Weather Bureau officials at the local offices in Nantucket, Atlantic City, and New York City, all of whom have furnished data used in this study. He is particularly indebted to those at Nantucket and Atlantic City for the large number of individual hourly temperatures furnished.

ADVANCE SHEET 1
JAN. 1917



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